

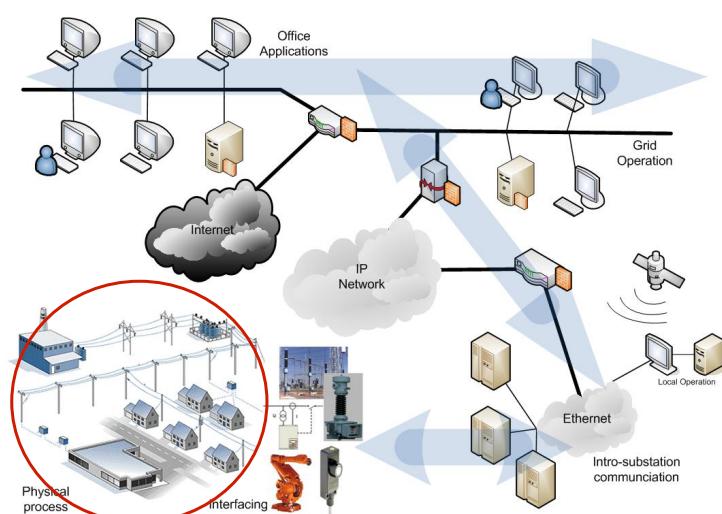
EH2741
Communication and Control in
Electric Power Systems
Lecture 3



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Course map



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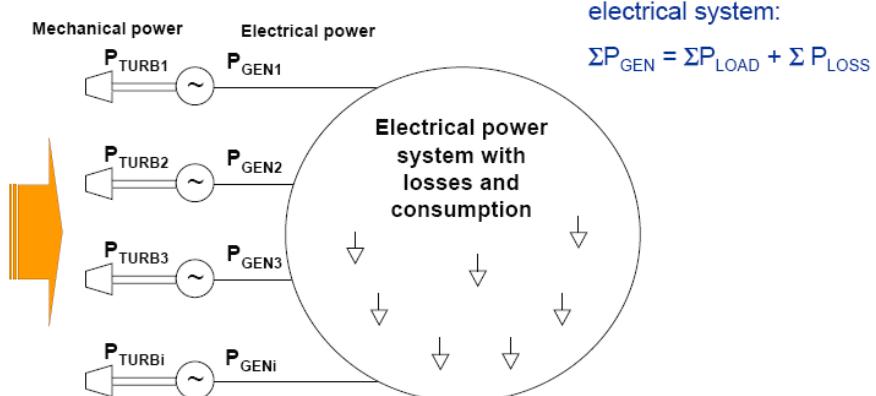
Outline

1. Repeating Power System Control
2. Power System Topologies
 - Transmission Grids vs Distribution grids
 - Radial grids vs Meshed grids
 - Line & Switchyard equipment
3. Power System Design
 - Reliability concerns
4. Substation Configurations
 - Reliable switching configurations



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Frequency Control



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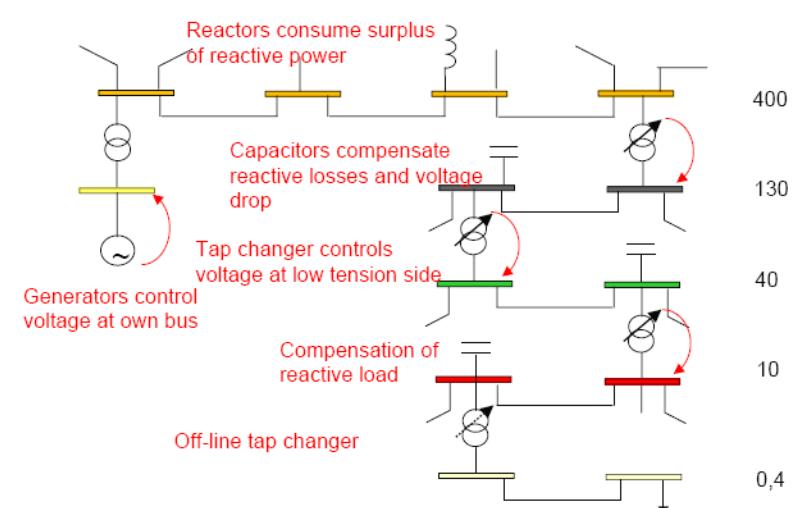
Tools for Voltage Control



- Main goal is to keep an even voltage profile.
- Generators with automatic voltage regulator (AVR) control voltage at generator bus
- Transformers with tapchanger. Step-wise control of voltage at one side
- Shunt reactors consume reactive power, which decreases the voltage
- Shunt capacitors produce reactive power, which increases the voltage
- Shunt compensation can be controlled
 - manually (from the control room)
 - with voltage automatic control
 - with time control
 - by a centralised logic

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Voltage Control Hierarchy



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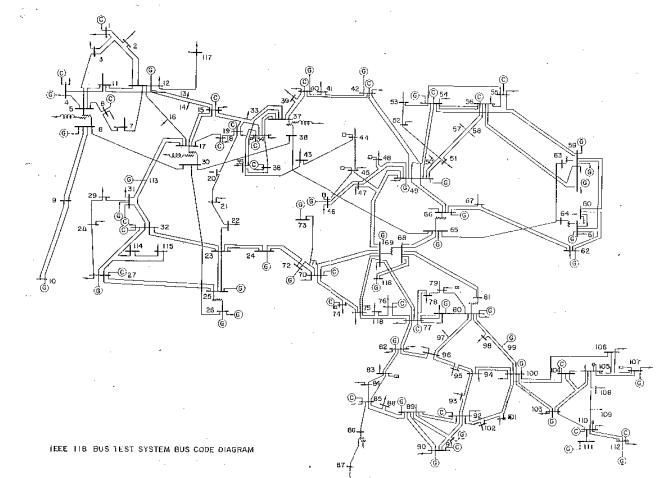
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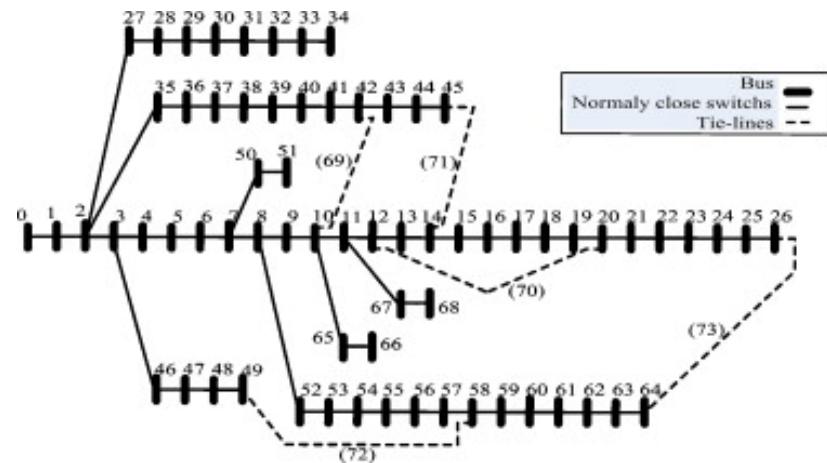
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Transmission Grids



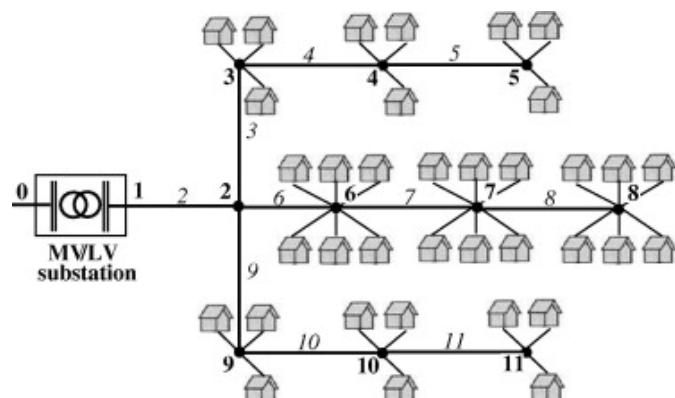
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Meshed MV Grid



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LV Feeders



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AC Power line



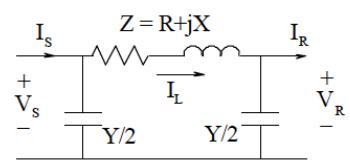
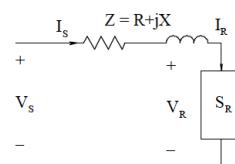
- Three phase AC
- Transfers energy with low losses
- Voltage levels from 0,4kV to 400 kV(+)

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PI model of Lines



- Short line models
- Medium line models
- Long line models
- Line parameters (Y, R, X) vary with line type

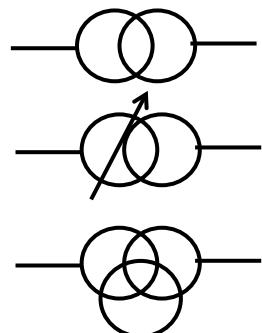


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Power Transformer

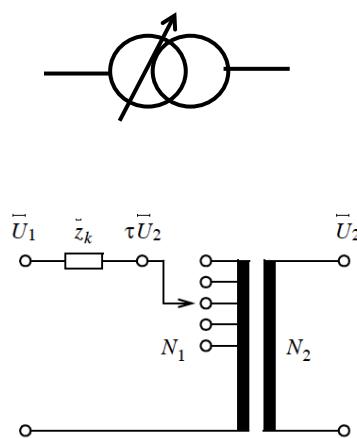


- Transfers energy between different voltage level
- Higher voltages are single pole
- Can shift phase angles



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Tap changer

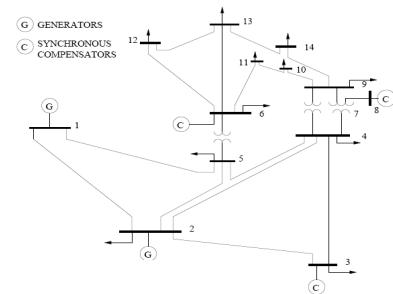


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Power System models

$$0 = -P_i + \sum_{k=1}^N |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik})$$

$$0 = -Q_i + \sum_{k=1}^N |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik})$$



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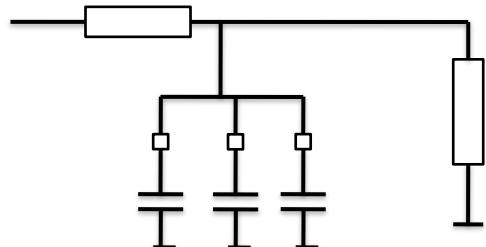
Series capacitor



- Compensates for inductance in long power lines
- Connected manually/mechanically

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Shunt capacitors



- Compensates for inductive loads by drawing leading current

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Shunt Reactance



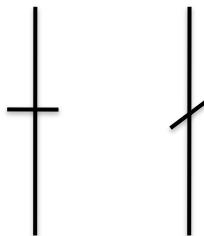
- Consumes reactive power
- Compensates for shunt capacitances in long power lines

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Disconnectors

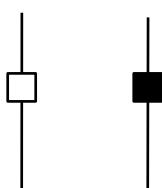


- Disconnects equipment
- Cannot break load currents



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Circuit Breakers



- Basic types divided according to how the arc is extinguished
 - Vacuum insulated
 - Gas insulated (SF6)
 - Oil insulated
 - Air insulated



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HVDC link



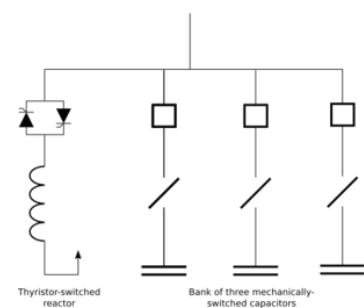
- Direct Current
- Rectifier stations convert to/from AC
- Controllable energy transfer with low losses
- No reactive components

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SVC



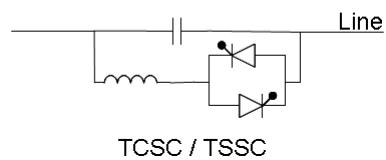
- Shunt capacitor with greater controlability
- Capacitor banks in parallel with thyristor controlled inductance
- Part of the FACTS concept



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TCSC – Thyristor controlled series capacitor

- Series capacitor with greater controllability
- Series capacitor in parallel with inductance
- Part of the FACTS concept



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Distribution Networks

- Design of Distribution Network varies significantly depending on:
 - Type of area(s) served
 - Voltage levels
 - Type of overlying network
 - Overhead or underground networks
 - Sizing of Distribution substations
 - Required performance of the network
 - Projected load growth
 - Losses
 - Historical/Cultural factors
 - Cost of installation
 - Cost of ownership



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Selection of Voltage level

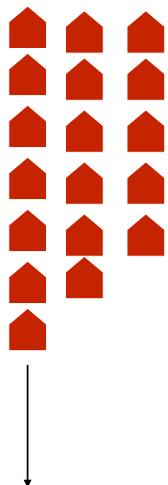
- What are the determining factors?
 - High voltage
 - Low losses
 - Low voltage
 - Less insulation problems, smaller equipment
- Other factors
 - Already installed equipment
 - Availability of spare parts, price,...
 - Overlying network
 - Distances



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Simple design example

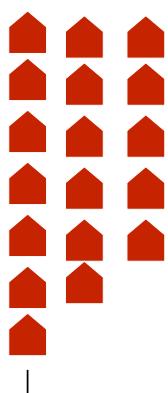


Assume 1600 loads
Located 40*40
Each at $S = 5$ kVA
Equidistant 25 m

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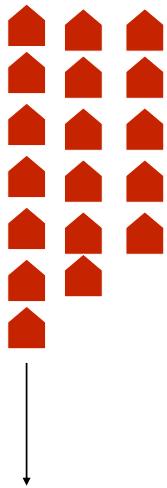
Small Distribution transformer



Assume 25 kVA trafo
5 Loads per transformer
320 substations
MV substation in center
2 MVA per feeder
80 substations per feeder

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Larger Distribution transformer



Assume 125 kVA trafo

25 Loads per transformer

64 substations

MV substation in center

2 MVA per feeder

16 substations per feeder

Etc..

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Adding some economic data



Trafo Rating (kVA)	Number	LV length (km)	MV length (km)	OH \$/kVA	Cable \$/kVA
25	320	32	9,7	128	670
125	64	38,4	8,9	80	338
250	32	39,2	5,1	68	275
500	16	39,6	4,5	77	248
1000	8	52	3,5	79	294

Assuming some typical budget figures for
MV & LV cables
MV & LV OH lines
Distribution Transformers

Example courtesy of "Control & Automation of Electric Power Distribution Networks" J Northcote-Green.

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Additional concerns

- In addition to cost of building and operating the distribution network, the reliability of the network is essential.
- A number of indices are used to determine the quality of service delivered.
- Additionally, regulators specify levels of quality and or cost caps that the distribution company must follow or be fined.

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System Performance Indices

- SAIDI
 - System Average Interruption Duration Index

$$\frac{\text{Sum of all customer interruption durations}}{\text{Total number of customers}}$$

- SAIFI
 - System Average Frequency of Interruption Index

$$\frac{\text{Total number of customer interruptions}}{\text{Total number of customers}}$$

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Customer Performance Indices

- CAIDI
 - Customer Average Duration of Interruption Index
 - $$\frac{\text{Sum of all customer interruption durations}}{\text{Total number of interruptions}}$$
- CAIFI
 - Customer Average Interruption Frequency Index
 - $$\frac{\text{Total number of interruptions}}{\text{Number of customers that have experienced an interruption}}$$
- CTAIDI
 - Customer Total Average Interruption Duration Index
 - $$\frac{\text{Sum of all customer interruption durations}}{\text{Number of customer that have experienced an interruption}}$$



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Some typical data (US)



Overall Averages of Sustained Reliability Indices from January 1 st – December 31 st 2002				
SAIFI (Interruptions Per year)	SAIDI (Minutes per year)	CAIDI (Minutes)	CTAIDI (Minutes)	CAIFI (# of Sustained Interruptions)
3.25	64.58	66.32	23.15	2.10

Overall Averages of Sustained Reliability Indices from January 1 st – December 31 st 2000				
SAIFI (Interruptions Per year)	SAIDI (Minutes per year)	CAIDI (Minutes)	CTAIDI (Minutes)	CAIFI (# of Sustained Interruptions)
4.68	55.88	91.03	17.81	10.67

Source: APPA 2003: Distribution System Reliability & Operations Survey
<http://www.appanet.org/files/PDFs/Strange2004.pdf>

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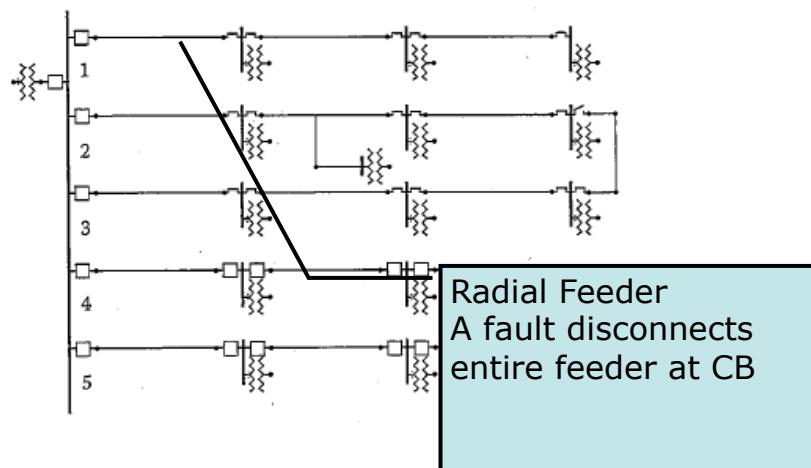
Main challenge for DSOs



- Designing and operating a distribution network at low cost while maintaining high level of reliability

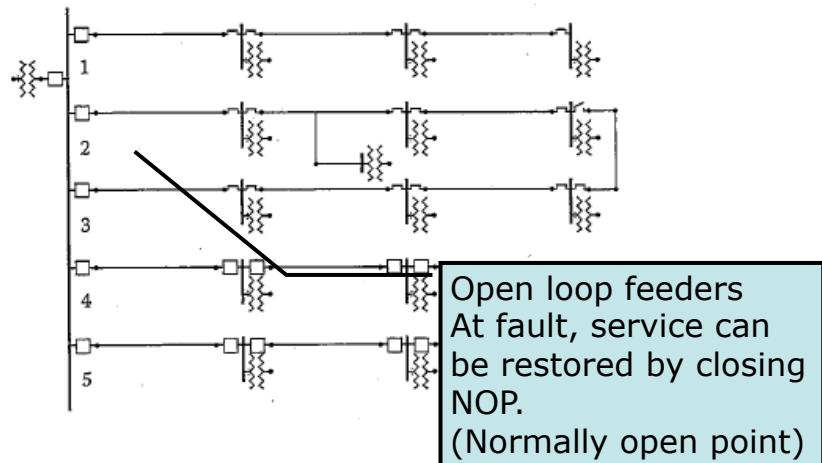
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Underground distribution net



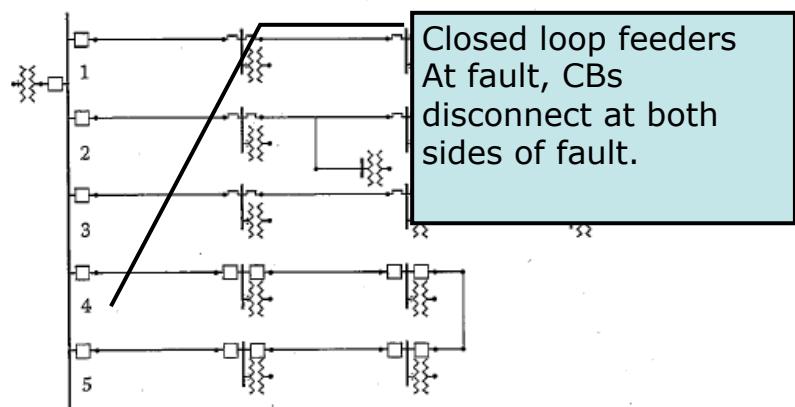
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Underground distribution net



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Underground distribution net

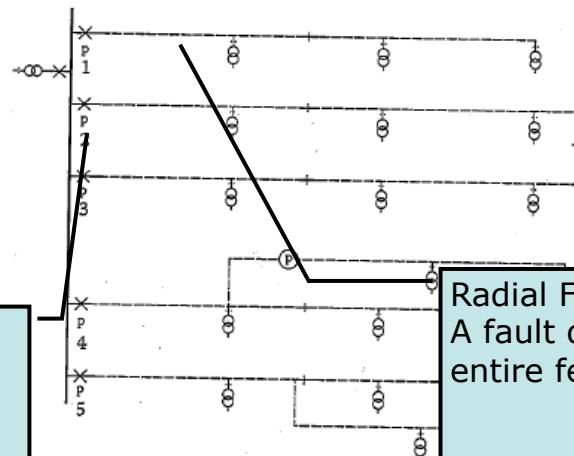


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Typical Overhead network

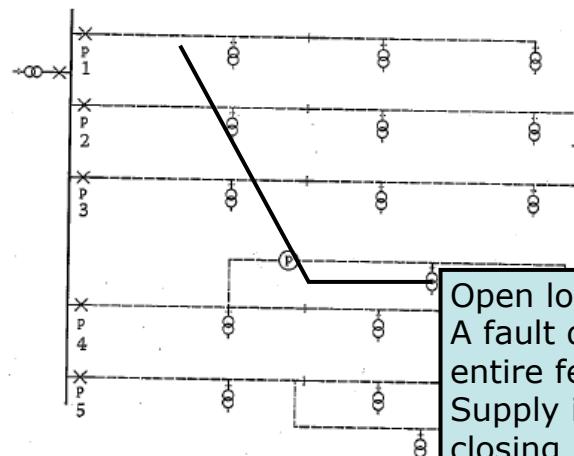


CBs with
Auto
reclosers



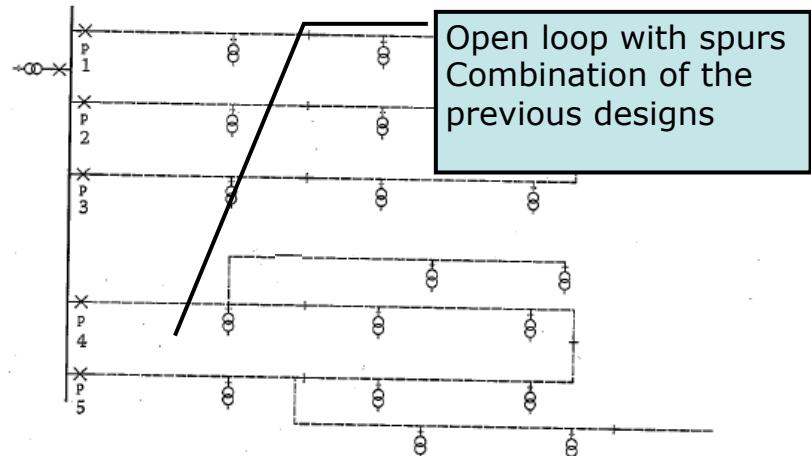
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Typical Overhead network



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Typical Overhead network



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Transmission Substation



Open air, vacuum
insulated



- Gas Insulated

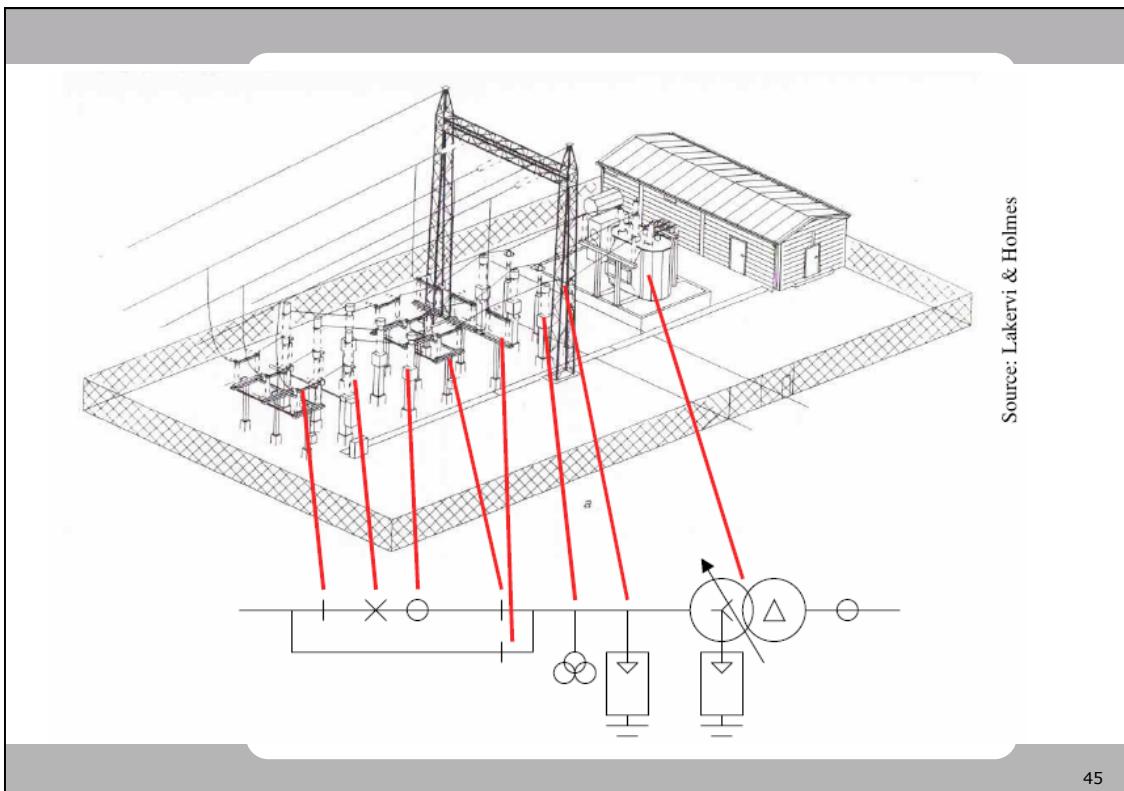
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Distribution Substation



- 10 - 25 kV range
- Equipment housed in compartments
- Separate compartments for
 - Disconnector
 - Breaker
 - Feeder
 - Measurement

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Evaluation Criteria



- Reliability
- Operation Flexibility
- Maintenance Flexibility
- Costs

Single Bus Configuration

**Advantages:**

- Lowest cost
- Small land area
- Easily expandable
- Simple in concept and operation

Disadvantages:

- Single bus arrangement has the lowest reliability
- Failure of a bus fault causes loss of entire substation
- Maintenance switching can complicate

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Sectionalised Bus

**Advantages:**

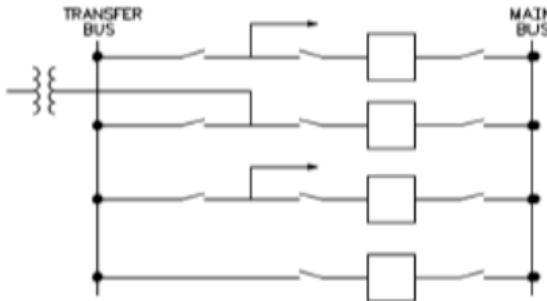
- Flexible operation
- Isolation of bus sections for maintenance
- Loss of only part of the substation for a breaker failure or bus fault

Disadvantages:

- Additional circuit breakers needed for sectionalizing, thus higher cost
- Sectionalizing may cause interruption of non-faulted circuits

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Main & Transfer Bus



Advantages:

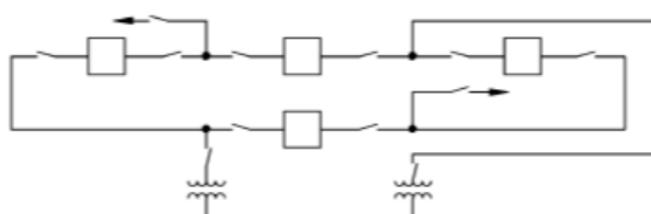
- Maintain service and protection during circuit breaker maintenance
- Reasonable in cost
- Fairly small land area
- Easily expandable

Disadvantages:

- Additional circuit breaker needed for bus tie
- Protection and relaying may become complicated
- Bus fault causes loss of the entire substation

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Ring bus configuration



Advantages:

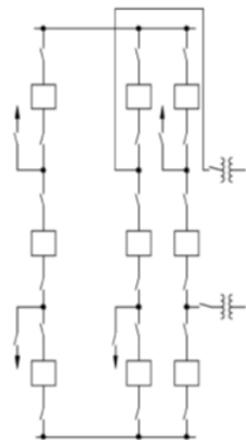
- Flexible operation
- High reliability
- Double feed to each circuit
- No main buses
- Expandable to breaker-and-a-half configuration
- Isolation of bus sections and circuit breakers for maintenance without circuit disruption

Ring Bus Disadvantages:

- During fault, splitting of the ring may leave undesirable circuit combinations
- Each circuit has to have its own potential source for relaying
- Usually limited to 4 circuit positions, although larger sizes up to 10 are in service. 6 is usually the maximum terminals for a ring bus

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Breaker & a half configuration



Advantages:

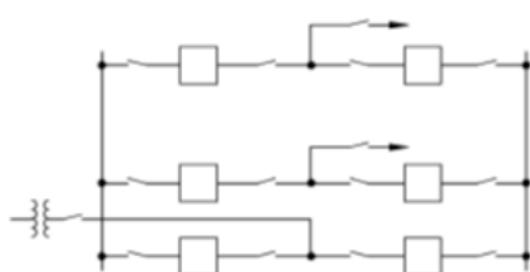
- Flexible operation and high reliability
- Isolation of either bus without service disruption
- Isolation of any breaker for maintenance without service disruption
- Double feed to each circuit
- Bus fault does not interrupt service to any circuits
- All switching is done with circuit breakers

Disadvantages:

- One-and-a-half breakers needed for each circuit
- More complicated relaying as the center breaker has to act on faults for either of the 2 circuits it is associated with
- Each circuit should have its own potential source for relaying

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Double breaker



Advantages:

- Flexible operation and very high reliability
- Isolation of either bus, or any breaker without disrupting service
- Double feed to each circuit
- No interruption of service to any circuit from a bus fault

Disadvantages:

- Very high cost – 2 breakers per circuit

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Questions or comments?